

EXTENDED ATTENTION SPAN TRAINING SYSTEM

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ABSTRACT

Attention-deficit Disorder (ADD) is a behavioral disorder characterized by the inability to sustain attention long enough to perform activities such as schoolwork or organized play. Treatments for this disorder include medication and brainwave biofeedback training. Brainwave biofeedback training systems feed back information to the trainee showing him how well he is producing the brainwave pattern that indicates attention. The Extended Attention Span Training (EAST) system takes the concept a step further by making a video game more difficult as the player's brainwaves indicate that attention is waning. The trainee can succeed at the game only by maintaining an adequate level of attention. The EAST system is a modification of a biocybernetic system that is currently being used to assess the extent to which automated flight management systems maintain pilot engagement. This biocybernetic system is a product of a program aimed at developing methods to evaluate automated flight deck designs for compatibility with human capabilities. The EAST technology can make a contribution in the fields of medical neuropsychology and neurology, where the emphasis is on cautious, conservative treatment of youngsters with attention disorders.

ATTENTION MANAGEMENT AND AUTOMATION

The management of attention is important for success in a wide range of endeavors from sport to study. The ability to remain aware of fluctuating attentional states, the ability to maintain effective states, and the ability to recover efficiently from attention lapses are valuable in task settings requiring recognition and response. In addition to personal differences in these abilities, there are also differences in the nature of tasks that either foster or discourage effective attention. The advertising industry has developed a technology of manipulating attention and awareness using presentation characteristics such as pacing, sequencing, complexity and color.

As automated systems become more capable, human operators spend less time actively controlling such systems and more time passively monitoring system functioning. This type of task demand challenges human capability for sustained attention.

Attention may be usefully characterized by three aspects: 1) distribution (diffused versus concentrated); 2) intensiveness (alert versus inattentive); and 3) selectivity (the "what" of attention) [3]. Distribution and intensiveness are influenced by the state of awareness being experienced, and selectivity refers to the contents of awareness. In designing for effective integration of human and system, it is important to provide ready access to useful information so that the contents of awareness support informed action. It is also important to design for human involvement in system function to promote effective states of awareness; i. e., to promote consistent mental engagement in the supervisory task. Mental engagement in automated environments may be enhanced by judicious allocation of task responsibility between the human and the automated system.

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A description of the biocybernetic system will provide the background for understanding how an adaptive task regulated by electrical brain activity forms an environment for training attention skills.

A BIOCYBERNETIC ASSESSMENT SYSTEM

The Automated Task Environment

A methodology and system have been developed to support the determination of optimal human (manual)/system (automated) task allocation "mixes," based upon a brain activity criterion of consistent mental engagement. In this methodology, an experimental subject interacts with a set of tasks presented on a desktop computer display while the subject's electrical brain activity is monitored.

This evaluation methodology has been developed in the context of computer-assisted flight management. The tasks in the set, the Multi-Attribute Task (MAT) Battery [2], are designed to be analogous to tasks that crew members perform in flight management. The MAT Battery display, depicted in Figure 1, is composed of four separate task areas, or windows, comprising the monitoring, tracking, communication, and resource management tasks. Each task may be fully or partially automated. The monitoring subtask (upper left window) requires a subject to detect warning light changes and scale pointer offsets. When this subtask is automated, these events are responded to by the computer. The compensatory tracking task (upper middle window) requires a subject to keep a moving symbol within a central rectangle. This task is automated by constraining movement of the symbol in one or both axes to within the central rectangle. The communications task (lower left window) requires a subject to discriminate an auditory message intended for his flight from other messages and to follow the message command to set radio frequencies. When this subtask is automated, the frequencies are set automatically when the message is received. The resource management subtask (lower middle window) is presented to subjects as a fuel management task. A subject is required to maintain a prescribed level in each of two tanks by controlling pumps from reservoirs. The computer maintains the levels when the task is automated.

The level of automation of the task battery may then be varied so that all, none, or a subset of the system control functions require subject intervention. This variable automation feature enables a range of levels of demand for operator involvement in system management to be imposed. Corresponding to these levels of involvement are degrees of mental engagement that are often spoken of in terms of being "in" or "out of the loop." Mental engagement in an automated task may not be sufficient to promote an effective state of awareness. Monitoring brain activity provides a window through which to view the experiential states of a subject in this situation.

The Electroencephalographic Engagement Index

The electroencephalogram (EEG) or brainwave has long been used to index states of consciousness or awareness. Stages of sleep are readily mapped by analyzing the frequency content of the electrical activity of the brain. Less well studied are the stages of waking consciousness. However, recent work [8] has identified characteristic patterns in three established brainwave frequency bands that distinguish among various states of attention. Relatively greater beta (13-20 Hz) activity has been observed for vigilant states, whereas alpha (8-13 Hz) activity predominates in alert but less mentally busy states, and theta (4-8 Hz) activity rises as attention lapses. These brainwave-state correspondences have proven useful in assessing attention-related disorders [5] as described below. However, within these guidelines there are significant individual differences. The set of frequency bands and recording sites that discriminate best among states of awareness for one individual are not likely to be the same set for another. Therefore, to derive an EEG index of attention with which to assess mental engagement in a task, it is necessary to develop each subject's EEG-to-state mapping profile.

This profiling procedure is conducted in the task environment described above. The procedure involves recording topographical EEG data from 19 electrode sites while a subject performs the MAT battery. The MAT is systematically stepped through its range of automation levels. At each step, a spatial map of EEG activity is generated for each of the alpha, beta, and theta frequency bands that portrays the scalp distribution of activity within that band. In this way, a trio of brainmaps is generated that corresponds to the state experienced at each level of task

automation. The EEG data represented in the entire set of brainmaps are used to derive state discriminant functions for the subject.

Once an individual subject's characteristic mapping profile has been determined, an index is constructed which is designed to be maximally sensitive to changes in state. The index has the form:

$$(K_1 * bS_1) / (K_2 * aS_2 + K_3 * tS_3)$$

where bS_1 = beta activity at electrode site 1
 aS_2 = alpha activity at electrode site 2
 tS_3 = theta activity at electrode site 3

with S_1 , S_2 , and S_3 representing the sites at which the activity in the associated band is most discriminating among states and K_1 , K_2 and K_3 are coefficient weights that reflect the relative contributions that the three band/site factors made to the discrimination. This index is constructed to have higher values for subject states corresponding to greater degrees of mental engagement; i. e., greater demands for operator involvement.

The Adaptive Task Concept

The engagement index is next employed with the MAT battery in a closed-loop control paradigm to observe the effects of adaptively allocating task responsibility between operator and automated system (Figure 2). That is, the task battery is adapted to the subject's degree of engagement in the task by assigning an additional subtask to the subject when it is determined that task engagement is waning over a time interval (Figure 3). Conversely, when the engagement index exhibits a sustained rise, indicating that the subject is capable of monitoring attentively, an additional battery subtask is automated. In this way, the feedback system eventually achieves a steady-state condition in which neither sustained rises nor sustained declines in the engagement index are observed. The combination of automated and manual subtasks, the task "mix," that the subject is presented in this condition may be considered optimal by the criterion of mental engagement reflected in the EEG state index.

This adaptive process is essentially a feedback control process whereby the reference EEG condition, stable short-cycle oscillation of the engagement index, is achieved by systematic adjustment of task demand for operator participation. EEG parameters have been used similarly as control variables in the critical administration of anaesthesia. In that application, closed-loop feedback control methods compare the set-point of the control variable, e. g., median EEG frequency, with the value actually measured to modify rate of drug delivery [7].

The adaptive system is designed to evaluate automated task environments to determine the requirements for operator involvement that promote effective operator awareness states. However, the assessment procedure may function as a training protocol in that the subject is rewarded for producing the EEG pattern that reflects increasing attention level by having the automated system share more of the work. With practice, a subject may learn how to deliberately control subtask allocation to the level at which he prefers to work. This observation led to consideration of the adaptive task concept for an attention training application.

THE EXTENDED ATTENTION SPAN TRAINING (EAST) SYSTEM

Biofeedback Training For Attention-deficit Disorder

Symptoms of pure Attention-deficit Disorder (ADD)--short attention span and poor focusing and concentration skills--are present in a majority of children who are hyperkinetic, or who have a specific learning disorder or who exhibit a conduct disorder [1] [5]. Lubar [5] and coworkers have found that topographic brain mapping of EEG frequency bands discriminates between children classified as pure ADD and matched controls, and that the discriminations are stronger during task performance than during baseline conditions. ADD children showed greater

increases in theta activity and decreases in beta activity during tasks. These findings strengthened the rationale for providing EEG biofeedback training to reverse these brain activity trends and improve attentional abilities.

Training is accomplished by providing the student with a real-time display of the levels of beta and theta activity being produced. The display serves as both information and reward for the child's efforts to reduce theta activity and increase beta activity. Success at producing the desired brain activity changes as well as improvements in psychometric performance have been reported as outcomes of training [5].

Mulholland [6] described a system for visual attention training using alpha activity as the control variable. Lubar [5] specifically recommends the use of theta/beta and alpha/beta ratios similar to the engagement index described above as sensitive discriminators of ADD. The Extended Attention Span Training (EAST) system uses brain activity band ratios in a training protocol that also employs the adaptive task concept.

The Attention Training Video Game

The MAT environment can serve as an attention training system as explained previously. However, the mission of achieving uneventful flight is likely to be less motivating to youngsters than winning at a dynamic, competitive video game. The EAST system is a prototype game environment intended to demonstrate the application of the adaptive task concept in a training format appealing to children. The video game platform selected presents a space battle scenario in which the player pilots a fighter ship in an attempt to reach and explode an enemy base while warding off attacks from the base's defenders. The action is viewed through a sighting window with cross-hairs. Other data such as range to targets, speed and weapons status are presented onscreen (Figure 4). A joy-stick is used to acquire and fire upon targets.

For the EAST application, the game is reprogrammed to impose an additional criterion for success. The game is made virtually impossible to win due to the evasive maneuvering and overwhelming number of the defenders. However, as a player concentrates and focuses better, the defenders maneuver less and there are fewer of them. Therefore, as the player does better at maintaining attention, the manual part of the game is made more manageable. The player learns that winning is contingent upon maintaining attention even as the game becomes less compelling. The attentive state is explained to the player as a special mental power, that is, being attentive is invoking this power to aid in winning. This is accomplished by programming the number and movement of targets to be a function of an attention-sensitive EEG band ratio. The EEG signal is sensed at a single scalp site and conditioned by an inexpensive isolated interface [4] into the game computer serial port. Frequency analysis, ratio calculation and game control are accomplished in software.

The next phase of work will evaluate the benefits of the adaptive task concept for attention training with a clinical population. It may be that the most effective use of the EAST system would be to augment current biofeedback paradigms for Attention-deficit Disorder by providing a rewarding environment in which trainees can demonstrate and improve skills learned in prior training. To offset the effects of ADD, EEG biofeedback must be integrated into an academic skills program including reading, mathematical skills and attention skills. The EAST technology represents a prototype of a new generation of computer game environments that teach valuable mental skills beyond eye-hand coordination. The technology can make a contribution in the fields of medical neuropsychology and neurology, where the emphasis is on cautious, conservative treatment of youngsters with attention disorders.

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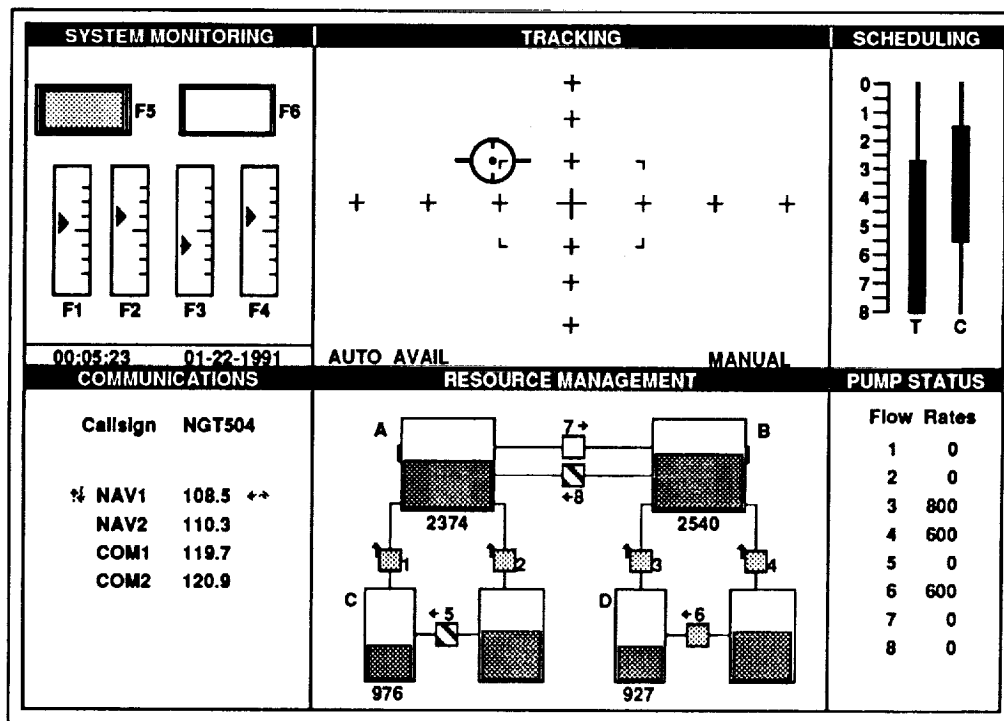


Figure 1. Multi-Attribute Task Battery Display

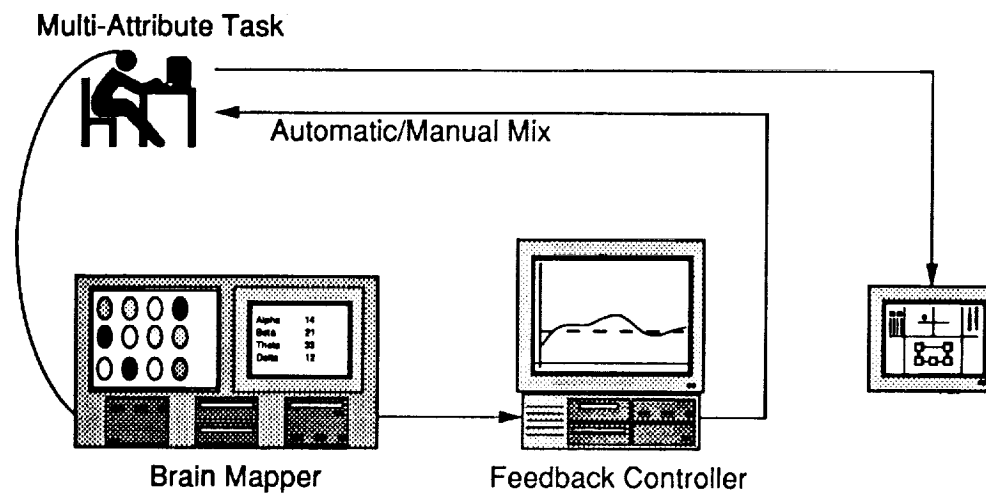


Figure 2. State-Contingent Adaptive Task Environment

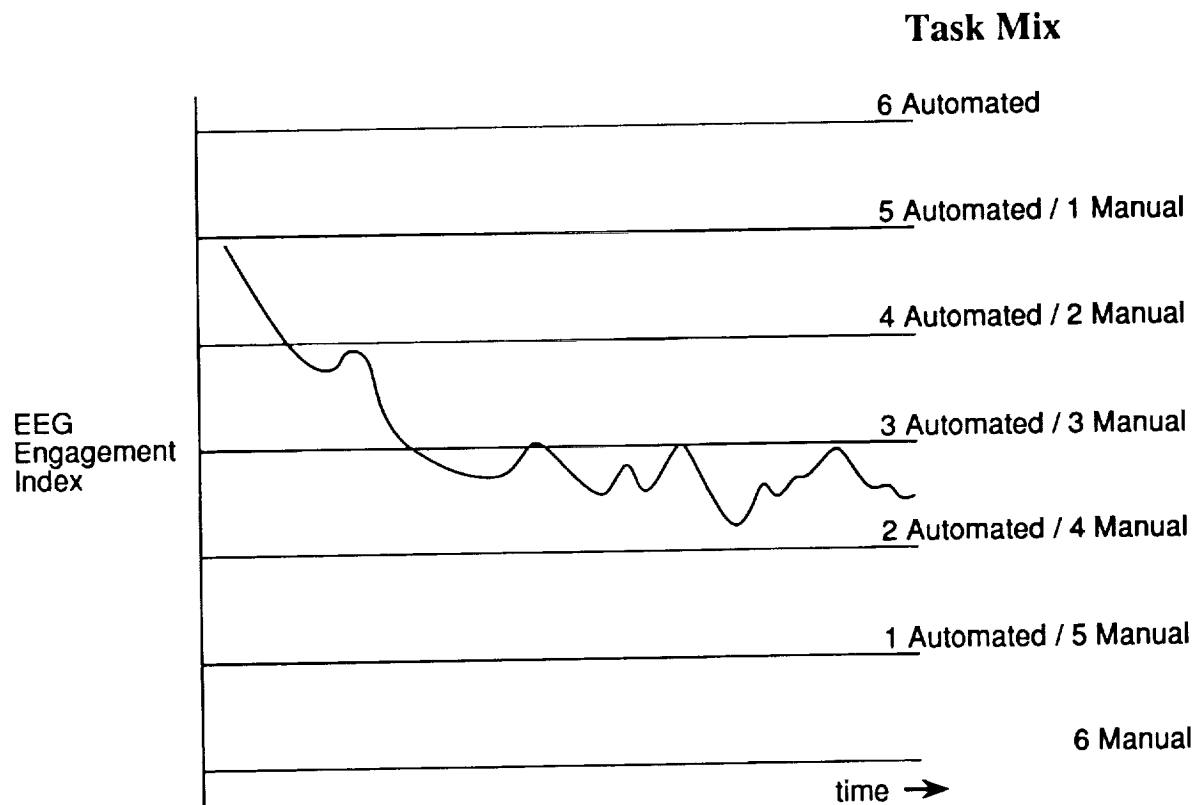


Figure 3. State-Contingent Adaptive Task Behavior for Automation Assessment

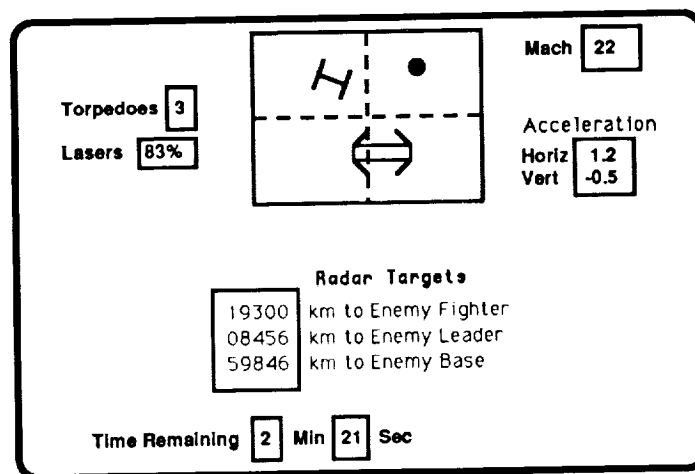


Figure 4. EAST Game Display